

The Development of the Quartz Crystal Oscillator Industry of World War II

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Abstract—This paper offers a history of a critical episode in military and electronics history—the difficult creation of quartz crystal frequency control units for radio communications during World War II. As a means of controlling the frequencies of radio transmitters and receivers, amateur radio hobbyists quickly accepted the quartz crystal oscillator after its initial development in the late 1920s. The military, however, declined to adopt this technology until just prior to World War II. Due to the small market for crystal oscillators, no mass production industry had ever developed to produce this extremely high precision electronic component. As war engulfed the nation, the U.S. Army Signal Corps found itself in the dangerous position of having gambled the integrity of its communications equipment on a component that could not possibly be produced in the quantities immediately needed. This paper looks at the challenges the United States faced in building a crystal manufacturing capability and in supplying this industry with sufficient supplies of raw quartz. A fairly specialized component of communications technology emerged from spare beginnings in prewar amateur radio to become the very foundation of a wide range of electronic devices today.

I. PROLOGUE

APRIL 1943. When the call from the Pentagon came to the Science Department at Colorado A&M, the secretary knew she needed to act fast. Hurrying down the hall, she interrupted professor Virgil Bottom's physics class and informed him of the call. Walking back toward the office, Bottom wondered and worried what the call could be about. The caller, Dr. Karl Van Dyke, quickly got to the point. "Do you have experience with using quartz oscillators for radio frequency control?" "Yes I do," was Bottom's reply. "How soon can you be in Washington?" was Van Dyke's next question.

Van Dyke, a former student of Walter Cady and an accomplished researcher in frequency control, was currently the Chief Physicist for the U.S. Army Signal Corps' Quartz Crystal Section (QCS). The QCS had been formed in response to a critical shortage of crystal oscillators, and Van Dyke was attempting to recruit all of the knowledgeable physicists, engineers, and geologists he could in order to resolve the crisis. Responding to this call for service, Bottom caught a train to Washington the day after the semester ended and began an assignment that would last for the remainder of the war, and a career that would last for the remainder of the century.

II. INTRODUCTION

Radio communications, as both a technology and an economic industry, developed very rapidly during the early decades of the twentieth century. From commercial radio stations to the two-way radio systems of police, taxis, and aircraft, the civilian market embraced wireless radio technology with enthusiasm. The military, however, with its ever-present fear of interception and compromise, was loath to trust its communications to anything other than wires strung between users. The development of the highly mobile air and armored branches of the military ultimately convinced the powers-that-be that the switch to wireless communications had to be made. Though the decision was made in the 1920s to utilize radio, it was still a very conservative decision in that the technology adopted was not exactly what would be called "state of the art."

The most critical component of a radio receiver or transmitter is that which controls the operating frequency. Several different techniques existed at the time for frequency control, the simplest being a combination of coils and capacitors. Though an acceptable method in theory, in practice such methods were found to be less than dependable (as they were susceptible to the effects of temperature, humidity, and physical handling). With the coming of the armored and air branches of the Army, the need for a truly stable, physically robust method of frequency control became paramount. The engineers of the Signal Corps turned their attention, at long last, to the use of oscillators utilizing thin wafers of quartz crystal.

Quartz crystal oscillators had been around for quite some time, though they had seen real use only in the commercial and ham radio communities. However, after field maneuvers in the summer and fall of 1940 showed the oscillators to be vastly superior to other means of frequency control, the military finally made the decision to switch to crystal units as their primary means of frequency control. This decision was not without its risks. Due to the relatively small market for crystal units, no real "industry" had ever developed for their manufacture (crystal units at this time were primarily produced one-at-a-time, by hand, in a very artisan, rather than mass production, approach).

III. FORMATION OF THE QUARTZ CRYSTAL SECTION

The Signal Corps planners, though possibly too optimistic about the nation's capacity for producing crystal oscillators, did plan to develop the small collection of crystal

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producers into an actual industry. With the coming of war in December 1941, this effort achieved significant importance. Whereas the production of crystal oscillators had never exceeded one hundred thousand in any given year, the military now needed millions of units and needed them urgently.

Thus, the Quartz Crystal Section (QCS) was formed in March 1942 under the control of the U.S. Army's Chief Signal Officer. Initially composed of two officers and eleven civilians, it grew to a staff of forty by June 1942 and ultimately comprised 72 members. The purpose of this section was to collect, collate, and then distribute the available information on crystal oscillator science, engineering, and production. Furthermore, they were tasked with developing machinery and techniques to mass-produce the crystal units. To assist with this effort, a crystal laboratory group was formed at the Signal Corps General Development Laboratory in Ft. Monmouth, NJ. This group eventually outgrew its facility and moved into an abandoned department store in Long Branch, NJ, occupying a floor once dedicated to the sale of toys. (With much of the previous stock still on hand, these engineers carried on their battle against the Axis powers amid rocking horses and doll houses.)

Any one with a professional connection to quartz, quartz oscillators, or radio electronics was instantly needed for staffing the QCS. Original members of the section included mineralogists such as Clifford Frondel and Dick Stoiber, geologists such as Wally Richmond and Hugh Waesche, and physicists such as Van Dyke and Bottom.

During the summer of 1942, the QCS distributed its first results to the crystal manufacturers in the form of a 200-page book. An additional publication was released the following February. Thereafter through August of 1944 the QCS provided supplemental information periodically. The Signal Corps laboratories also contributed to the dissemination of information. Over the course of the war, the Camp Coles Signal Lab produced twenty-one publications concerning equipment, manufacturing, and testing techniques. Furthermore, both information and equipment "pools" were created to serve as resources for manufacturers new to the field of crystal oscillators. The information pool consisted of technical data collected from manufacturers, some of it donated directly by the manufacturers and some gleaned by Signal Corps inspectors as they traveled the country. The equipment pool was an attempt by the Signal Corps to impose some sort of standardization of equipment and technique on the industry. The Defense Supplies Corporation underwrote the costs for this equipment pool. Over the course of the war, approximately 36 companies took out contracts through this program at a cost of \$1.5 million.

Once the work of the section was underway, members began to travel the country serving as consultants and troubleshooters for the new manufacturing companies. These efforts were extremely successful, with both quantity and quality of produced oscillators regularly exceeding Signal Corps requirements. Within the first year of the war, the newly formed industry produced over six

million units (ultimately producing at four times that rate by war's end).

IV. GOVERNMENT RESPONSE TO CRYSTAL SHORTAGES

The early months of the war were characterized by shortages of valuable commodities, and crystal oscillators were no exception. The primary government agency concerned with industrial production of war material was the War Production Board (WPB). Among its many and varied operations, the WPB paid a great deal of attention to the crystal shortage problem. The fundamental question facing the WPB was how to increase the supply of raw quartz for the nascent oscillator industry. Quartz had been recognized as an important "strategic or critical" resource as early as 1937 when it was included in the "Act to Expedite the Strengthening of the National Defense." It was also included two years later in the more powerful "Strategic Materials Act" of June 1939. Whereas the 1937 Act prevented the export of quartz from this country, the 1939 Act appropriated money (on the order of one million dollars) for its purchase and importation.

Natural "radio grade" quartz was found in any sizeable quantities only in Brazil. As soon as the decision to switch to crystal control was made, negotiations were initiated by the U.S. government to purchase as much of the production of Brazilian quartz as they could. By June of 1941, the U.S. had gained the rights to essentially all quartz mined in Brazil.

Securing the rights to buy the quartz and actually buying and transporting it back to the U.S. were two very different things. Through the Metals Reserve Company and the Reconstruction Finance Corporation, the U.S. Government went into the quartz importing business. Many problems were encountered along the way. The Brazilian quartz mining operations were far from being well-developed. In fact, a large fraction of the crystals eventually sold in Rio de Janeiro were collected by hand by local "garimpeiros" (diamond hunters) looking to trade them to merchants for food supplies or liquor. Dick Stoiber traveled to Brazil (on his very first airplane flight) to see what could be done about improving the mining situation. His recommendations for mechanized mining equipment were followed, though the remoteness of the region, conditions of the roads, and shortages of fuel for the equipment prevented any real improvements in the situation.

Once the crystals reached Rio, they had to be inspected for defects and graded as to their usefulness for radio electronics. As with most wartime goods, inflation took its toll; while the U.S. importers tried to set price ceilings, the Brazilian government continued to raise its legal price floor. Transporting the crystals to the U.S. presented its own host of problems. Transporting by ship was both time-consuming and dangerous. Time lost in waiting for a shipment was just as critical during the early months of the war as quartz lost to German U-boat attacks. Until the initial crisis passed, shipments were flown to the U.S. under the auspices of the Air Ferry Command.

The task of supplying the U.S. manufacturers with raw quartz was further complicated by the need to assist Great Britain in acquiring crystals for their radio industry and, possibly more importantly, for the manufacture of submarine detection equipment. The British constantly complained of the unfair competition they faced in the Brazilian market for raw quartz. However, their frequent calls to forbid private American firms from purchasing quartz went unheeded. The option of supplying the British needs from the U.S. stockpile was investigated, though disagreements between the representatives of the two countries over inspection techniques and quality ratings prevented the program from ever getting off the ground. Another thorn in the Americans' side was the British insistence on receiving only the largest and highest quality raw crystals. The fear that the British would skim off the cream of the U.S. stockpile was a primary consideration in rejecting the proposal. The British continued to procure their own raw quartz directly from Brazil, while the U.S. frequently responded to their emergency requests for raw quartz throughout the war.

Along with the concerns of buying and shipping raw quartz from Brazil, the WPB oversaw the search for domestic deposits. Quartz deposits had been discovered in the U.S. before World War II, but had never been exploited (primarily for lack of a suitable market). The two primary centers of these deposits were in California and Arkansas. Prewar reports existed in the files of the Naval Research Laboratory of a gold mine in Calaveras County, California, in which sizable amounts of quartz had been detected. The Reconstruction Finance Corporation made a loan of \$25,000 to the mine owners in hopes of developing it into a useful source of raw crystals. Unfortunately, neither this mine nor others nearby ever produced enough quartz to make the endeavor worthwhile. A more promising area for quartz prospecting was that of Hot Springs, Arkansas. Samples of crystals from known deposits showed encouraging results when tested by manufacturers. The government invested approximately \$150,000 in exploring likely sites and set up a quartz-purchasing program to stimulate private prospecting. However, the small size of the isolated quartz deposits led to the abandonment of this area as well. A private mineral firm from New York brought in a steam shovel and continued to work the deposits. They too gave up on the area after an expense of \$50,000. All in all, only five to six thousand pounds of satisfactory quartz were mined from this region.

V. INDUSTRIAL RESPONSE TO CRYSTAL SHORTAGES

Along with the responses of the U.S. government and military, members of the civilian quartz and radio industries also sprang into action. Perhaps none made a greater contribution to the solution of the crystal oscillator situation than Paul Galvin of the Galvin Manufacturing Corporation (now Motorola). Being one of the largest producers of radio equipment for the military, Galvin found itself

overwhelmed by orders at the start of the war. Knowing that his current suppliers could never meet his needs for frequency control components, Paul Galvin set about creating his own network of subcontracting producers. Some of those that answered Galvin's call for suppliers were established radio, or at least electronics, manufacturers. Others, put out of business by wartime restrictions or shortages of raw materials, had nothing more than an empty building, an idle work force, and a desire to remain solvent. From these beginnings, Galvin built a very successful network.

The fabled ingenuity of the American small businessman was never in evidence more so than in the quartz crystal field. Many of these new crystal manufacturers were able to contribute quickly to the rest of the industry by developing new machines or production techniques. Louis Patla, founder of DX Crystal Company of Chicago, invented a grinding machine from home workshop drill presses available at Sears & Roebuck in great numbers. These machines were able to grind dozens of crystal blanks at a time, helping to turn a one-order-at-a-time business into a truly mass production industry. Another similar invention was that of a polarized light instrument for inspecting raw crystals for defects, built using Polaroid sunglasses purchased at the local Walgreen's drug store.

In order to communicate information such as this to the rest of the industry, Galvin produced a *Crystal NewsSheet* which was distributed nationally. Such a level of subcontracting and intra-industry cooperation was very rare. Government agencies such as the WPB worked to foster this type of cooperative spirit throughout the varied industries contributing to the war effort. The formation of Industry Advisory Committees for many different industries fostered openness and communication between manufacturers across the country. The advisory committee for quartz crystals focused its energies primarily on the conservation of raw quartz and on the improvement of production techniques.

With the influx of new blood into the industry came a great many innovations in working with raw quartz. Initially, samples of quartz smaller than 500 grams were considered too small to be of use and were rejected by inspectors. Industry and government labs carried out simultaneous experiments to see if techniques couldn't be developed to take advantage of the large quantities of smaller crystals piling up in the industrial and governmental stockpiles. (In the words of one plant owner attempting to persuade another to try using the smaller crystals: "God made lots of small crystals but very few large crystals, so why don't you go along with God and use the small crystals.") Using X-ray orientation techniques, processes were developed for correctly positioning the crystals so that cuts could be made along the proper axes. Experiments were also carried out to ascertain just what effect the various flaws found in raw crystals had on the production and electronic uses of the quartz. The result was that a great many of the known flaws had little or no detrimental effect and thus thousands of pounds of previously classified "reject" crystals became

available for use by manufacturers. These discoveries essentially ended the supply crisis in the United States.

VI. AGING CRISIS

By mid-1943, it seemed as though the crisis had been alleviated. A group of crystal producers existed that could truly be referred to as a mass production industry, Signal Corps requirements were being met each month, and allied military forces were on the offensive all across the globe. However, reports were beginning to filter in describing unsettling failures in crystal oscillators; some would simply cease to oscillate, while others suffered a mysterious increase in their natural frequency. At first, the reports of this “aging” problem were discounted. No one in the Signal Corps labs could believe that such a thing could occur. Eventually though, the weight of the evidence forced them to face the issue and begin a crash program of research to find the root of the problem and effect a solution.

After having served as a QCS member in Washington and as a traveling consultant and troubleshooter, Virgil Bottom embarked on his third “mission” for the Signal Corps. Transferred to the Signal Corps Engineering Laboratory at Ft. Monmouth, NJ, Bottom was put in charge of investigations into the aging problem. Early work found that chemicals within the oscillator holders were reacting with the wiring, leading to the loss of vibrational activity. The change in natural frequency, however, was more complex. With most of the failure reports coming from very humid theaters of the war, Bottom developed a hunch that high temperatures and humidity were at the root of the problem. Utilizing a homemade test chamber referred to as the “swamp,” he found this to be the case.

Further investigation showed that during the grinding process of producing a crystal oscillator, tiny bits of quartz would become embedded within the surfaces of the wafers. Rapid oscillation, coupled with high heat and humidity would later cause these loose pieces of quartz to separate from the surface of the crystal, decreasing the mass of the wafer and increasing its natural resonating frequency. Bottom determined that etching the quartz wafers to final frequency using strong acids would avoid these loose particles and thereby alleviate the aging problem. Upon Signal Corps orders, all crystal producers began using this method of crystal finishing, effectively resolving the aging crisis.

VII. CONCLUSION

The effect of reliable communications to the highly mobile allied armies scattered across the globe is hard to overestimate. The radios within the planes and tanks and carried upon the backs of foot-soldiers were weapons, perhaps

not commonly recognized as such, but powerful weapons nonetheless. As Henry Klingler, a young tank commander from west Texas succinctly put it, “our communications helped win that war.”

As an industry, the quartz crystal electronics industry is unique. It essentially came into being as a result of the war. From its beginnings as a virtual cottage industry, it grew to encompass dozens of manufacturing plants all across the country, and produced millions of crystal oscillator units. Even before the official end of hostilities, however, the government contracts began to be canceled and most of the plants closed their doors. At the start of the war, there was no real industry to expand upon and none existing in any other countries to provide a blueprint from which to build one in this country. The crystal industry was essentially *invented* by a handful of engineers, scientists, and industrialists. Without the development of mass production machinery and techniques, the industry, large as it was at its peak, would not have been able to produce the numbers of crystal units needed by the military. Without the influence of the war, many of these techniques might never have been developed. They simply would not have been needed to supply the slowly developing civilian market. In fact, it is these mass production techniques which allow the still rather small industry (50 companies) today to keep pace with the much greater civilian demand for crystal oscillators (for consumer products ranging from computers to cell phones to color television sets).

Though a serious gamble at the time, the decision by the Signal Corps to switch to crystal control just before the war was the correct one. Though this might not have been clear to them in the beginning, these men came to understand just how important this decision was and how much the gamble had paid off. As Major General Roger Colton, Chief of the Signal Corps’ Engineering & Technical Service later stated: “Our decision to go into crystal-controlled radios for widespread tactical use has been more than justified by the results obtained. The Army had radio before they had crystals. Now the Army has communications. That’s the difference. Crystals gave us communications.”



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